CONCRETE PENETRATION AND RICOCHET TESTING OF TWO PROJECTILE TYPES

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ABSTRACT

The purpose of the work was to develop penetration/ricochet data for two projectiles launched against 5,000 psi concrete targets and, in addition, to measure the axial stress on the nose of a projectile during concrete penetration. The program employed projectiles 3.35 inches in diameter and approximately 27 inches long with two different nose shapes. Three different types of targets were used. Targets consisted of concrete slabs, 8-ft square and with thicknesses of 4 inches, 12 inches and 30 inches. A ricochet relation was developed from the data and the results seemed to correlate well with some previous work. One test was conducted in which an on-board shock resistant recorder was used to collect a time history of the output of a pressure transducer installed in the nose of a projectile. The results of the experiment were compared with a hydrodynamic code calculation and showed reasonable agreement for early times.

RICOCHET TESTING

Projectiles

The two types of projectiles used in the program are shown in Figure 1. Both projectile types were derived from the same basic design and had identical outside diameters and interior cavity geometries. The principal differences were in the nose shape and the aft baseplug design. The Type A projectile had a conical nose shape and had a baseplug which was screwed entirely into the aft end of the projectile until it was flush with the aft surface. The Type B projectile had a tangent ogive nose and included a baseplug which had an internal fitted threaded section and an aft closure equal to the outside body diameter of the projectile. The Type A projectile was approximately 27 inches long while the Type B was about 26.5 inches long with the baseplug installed. Both projectiles had blunt cylindrical nose tips 1 inch in diameter and were filled with a material that had a density of about 0.058 pounds per cubic inch (1.6 gms/cc). The projectiles were fabricated of E4340 steel, heat treated to a Rockwell C Scale hardness of 42 to 46. Total loaded weight was about 36 pounds for each projectile.

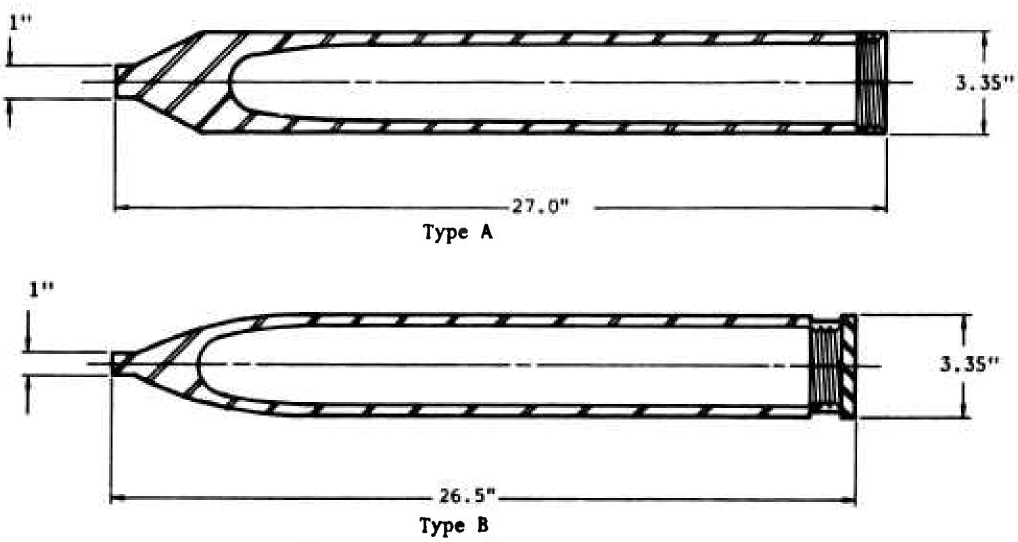


Figure 1. Projectile Geometries

Targets

All targets were constructed of concrete using a mix design intended to yield a compressive strength of 5,000 pounds per square inch (psi) after 28 days. The limestone aggregate was specified to have a minimum compressive strength of 17,000 psi and a maximum nominal size of 3/4 inch. The targets were square slabs, 8 feet on a side with thicknesses of 4 inches, 12 inches and 30 inches. All targets were cast as monolithic pours without internal interfaces. At the time of pouring, tensile beam and compressive test specimens were taken from the concrete of each target. The compressive strength samples were tested two at a time, at intervals of 7 days, 28 days, and 90 days after pouring with all of the remaining samples tested during the week that the targets were used. Figure 2 is a time history plot of the average compressive strengths for the 12-inch thick target. The others were similar.

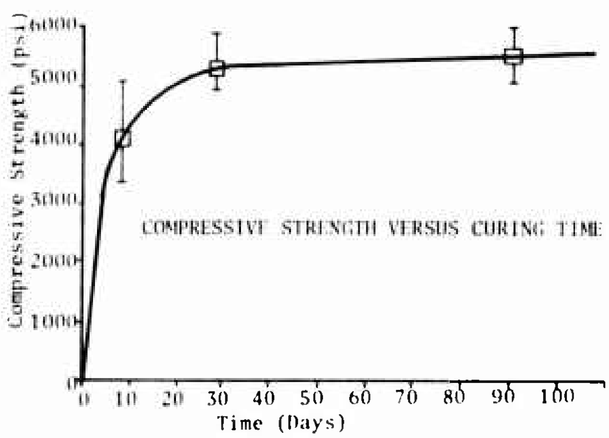


Figure 2. 12-Inch Thick Target Strength

Note that reinforcing rods were not used in the central area of the target. Figure 3 shows the geometry of a 12-inch thick target. The steel reinforcement was purposely omitted to insure that the ricochet data would be representative of the concrete and not be influenced by the steel reinforcement especially at the lower impact velocities. The lateral size of the targets, 8 feet on a side, was chosen to be as large as possible based upon the lift capability of a crane used to position the largest target which was 30 inches thick and weighed about 11 tons. In all tests, the distance from the centrally located impact point to the nearest edge was nominally 48 inches or about 14.3 calibers based upon a projectile diameter of 3.35 inches.

The final overall target configuration varied to the extent that the 4-inch and 12-inch thick targets were tested with the back side of each resting on a sandy clay soil surface, while the 30-inch thick targets were tested vertically with the back sides being free surfaces exposed to the air. The reason for the difference was that the two thinner targets were intended to represent poured slabs resting on the ground, while the 30-inch target was a better representative of a semi-infinite concrete target. Thus, all tests involving the 4-inch and 12-inch targets were actually concrete-soil combinations. The soil beneath each target was lightly compacted by repeatedly driving a vehicle over the surface after it had been built up to the proper angle.

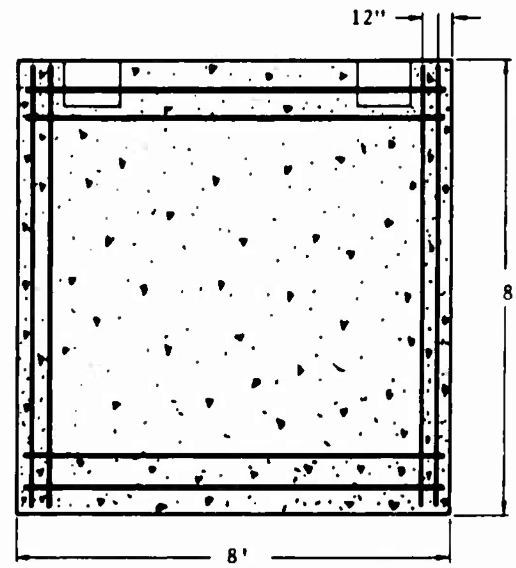


Figure 3. 12-Inch Thick Target Design

Test Arrangement

The projectiles were launched from a 155mm gun fitted with an internal barrel sleeve which reduced the bore to about 85mm (3.35 inches). The gun was mounted on the rear of a 5-ton truck chassis and was capable of being moved in elevation only. Azimuth changes were made by turning the truck. The alignment of the projectile trajectory to the target normal was made using a surveyor's transit and a steel measuring tape. The measurement scheme was capable of determining the obliquity angle to less than 0.2 degree. While the target position relative to the line-of-sight trajectory could be measured to this accuracy, the targets could only be located within 2 degrees of a desired angle because of the difficulty associated with positioning the targets and/or the gun any more precisely.

Two impact velocities were of interest, 700 feet per second and 1100 feet per second. Projectile velocity was changed by varying the powder charge in the gun. The velocity was measured using two high speed framing cameras along with chronograph measurements of time between screens placed in the projectile's flight path to the target.

The test approach was based upon the up and down method developed by Dixon in Reference 1. Obtaining the critical ricochet angle at each

test condition required at least one ricochet and one penetration within 10 degrees of each other. Then, if the outcome was a ricochet, the angle between the target normal and the projectile trajectory was decreased by 5 degrees for the next test at that target/velocity combination. Conversely, if the outcome of the previous test was a penetration, the angle would be increased by 5 degrees. This procedure was used until both a ricochet and a penetration event had occurred at that particular combination. Figure 4 is a schematic view of the overall test arrangement for the slab targets.

Although these tests were not part of the data base used to develop the equations, and the projectile geometries were considerably different from those used in Roecker's work, the correlation with this data shows good agreement. The equations, as currently defined, were not applied to the 30-inch target data since none of those projectiles penetrated in the target and either ricocheted or rebounded. The 30-inch data fit is the dashed line.

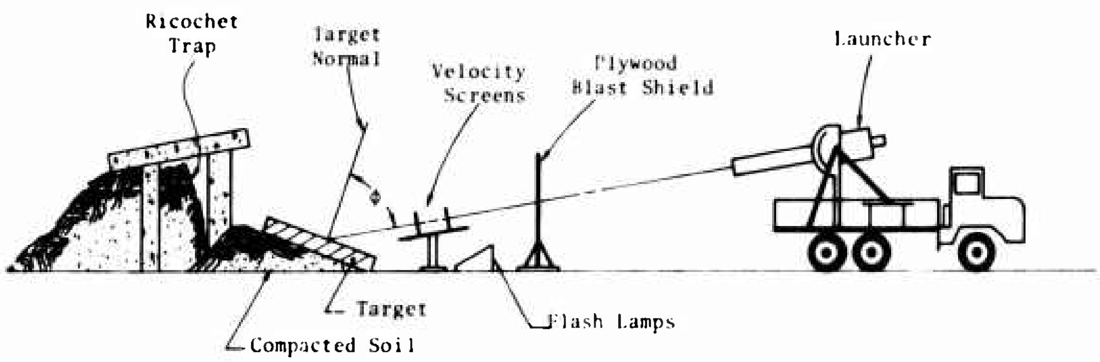


Figure 4. Overall Test Arrangement

Results

Tables 1 and 2 contain a summary of the test results for the Type A and B projectiles, respectively. It may be noted that for the 4-inch and 12-inch thick targets, all penetrations were actually perforations, since the projectile passed completely through the target and was recovered in the underlying soil. For the 30-inch thick targets, all of the penetrations were rebounds and none of the projectiles stuck in the target or passed completely through. In most cases, the rebounded projectiles were found lying on the ground in front of the target, within 25 feet of the impact point.

Figures 5 and 6 are plots of the test data for the Type A and B projectiles, respectively. The data for all three target arrays is plotted on each graph. The solid points indicate a penetration and the open points indicate a ricochet. More scatter is evident in the Type A projectile data than in the other. These projectiles were fired first and some difficulty was experienced in obtaining the desired launch velocity due to gas blowby in the gun. As a result, a number of velocity conditions were repeated. By the time testing began with the Type B projectiles, these problems had been overcome and launch velocities were more precise.

After the testing was completed and during our analysis of the test data, an empirical correlation developed by Roecker (Reference 2) became available. These equations were used to plot the solid lines in Figures 5 and 6.

The correlation developed by Roecker is still under development and will not be presented in this paper. However, some information can be stated. The critical ricochet angle is determined by summing three terms. The first term has a relationship which explains the changes in ricochet angle as a function of the ratio of target thickness divided by the major body diameter (T/D) and the ratio of body length divided by the major body diameter (L/D). The second term relates changes in ricochet angle due to projectile strength and is a function of (L/D) and the ratio of minimum wall thickness of the projectile to its major body diameter (W/D). The third term related the changes in the ricochet angle as a function of velocity squared. Terms due to nose shape or concrete strength are not included at this stage of development.

PENETRATION TESTING

Background

Penetration calculations conducted by Osborn using hydrodynamic computer codes (References 3 and 4) had resulted in a concrete loading model which could be used to predict the axial stress loading on the nose of steel projectiles penetrating concrete targets. The model was applicable for normal impacts in the range of 100 to 500 meters/second and considered both finite and semi-infinite targets. The hydrocode calculations indicated that the steady state axial stress on the nose of a blunt projectile entering a concrete target, would be less than 4.5 kilobars (65,000 psi) for impact

TABLE 1. TYPE A TEST SUMMARY

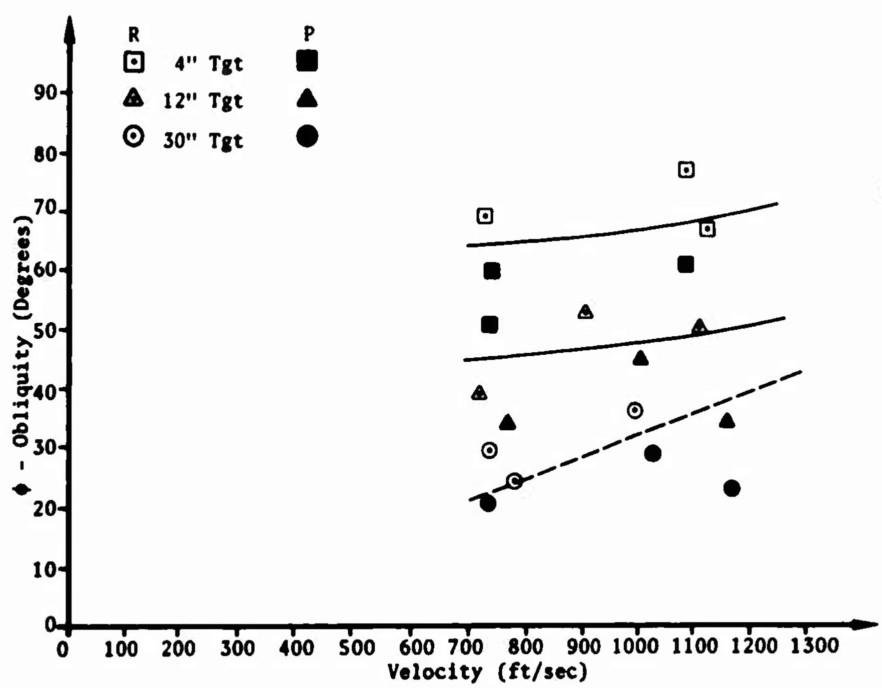
TARGET THICKNESS (INCHES)	VELOCITY (FT/SEC)	OBLIQUITY (DEGREES)	OUTCOME[1] (R OR P)
30	1167	23	P
30	1030	28.9	P
30	999	35.7	R
30	783	24.5	R
30	741	20.6	P[2]
30	740	29.3	R
12	1159	34.3	P
12	1005	45.0	P
12	910	52.9	R
12	721	39.4	R
12	768	34.4	P
4	736	50.9	P
4	748	59.9	P
4	728	68.9	R
4	1079	76.5	R
4	1118	66.6	R
4	1088	60.3	P
30	970	33.6	R
12	1113	50.1	R
30	1097	33.8	R

NOTES:
1- R indicates a ricochet; P indicates a penetration or rebound.
2 - Projectile was yawed 5 degrees at impact.

TABLE 2. TYPE B TEST SUMMARY

TARGET THICKNESS (INCHES)	VELOCITY (FT/SEC)	OBLIQUITY (DEGREES)	OUTCOME[1] (R OR P)
12	1185	50.2	R
12	1240	44.9	P
12	769	40.8	P
12	770	45.6	R
4	756	63.8	P
4	768	69.3	R
4	1186	70.8	R
4	1152	65.6	P
30	733	23.6	R
30	745	18.3	P
30	1094	35.6	P
30	1105	39.6	R

NOTES:
1 - R indicates a ricochet; P indicates a penetration or rebound.



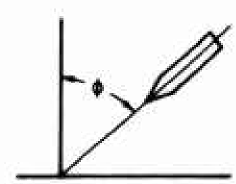


Figure 5. Type A Projectile Ricochet Data

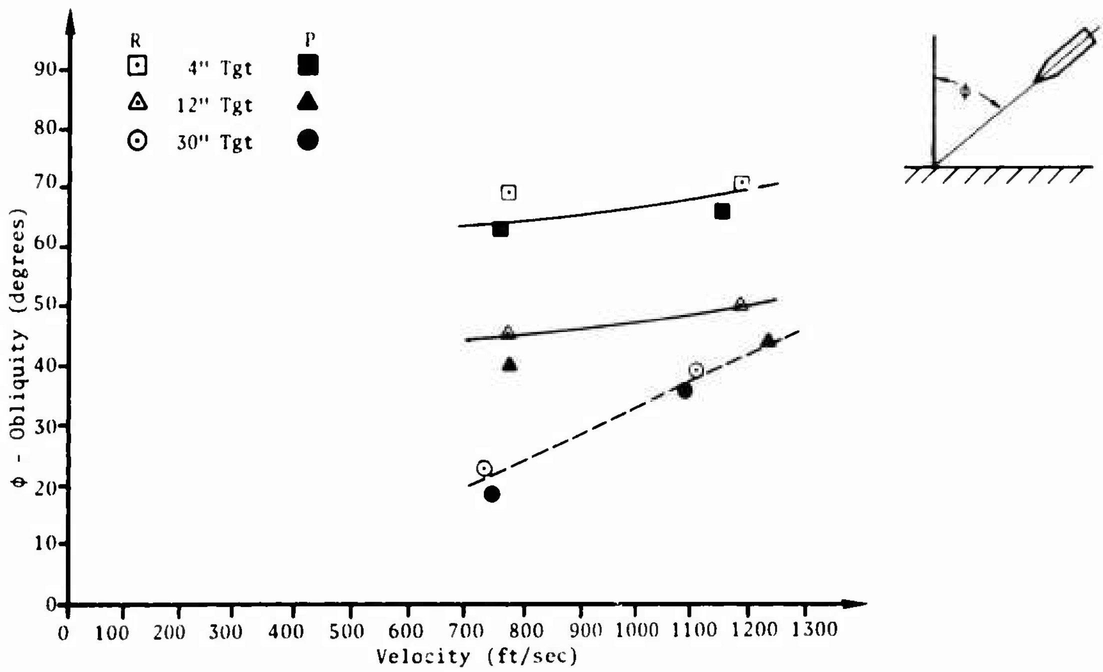


Figure 6. Type B Projectile Ricochet Data

velocities of less than 150 m/sec. Since pressure transducers used for ballistic applications are capable of reading pressures as high as 100,000 psi (6.9 Kbar) it appeared that, by including a recording package in a projectile and installing a suitable pressure transducer in the nose, it would be possible to obtain data which would confirm the basic aspects of the model and the concrete equation-of-state.

Instrumentation

The transducer selected was the Model 109A manufactured by PCB Piezotronics, a type ordinarily used to measure breech pressures in ballistic applications. The transducer features an internal transistor amplifier and is designed to withstand pressures as high as 100,000 psi, developing a low impedance output signal. The active element is a piezoelectric crystal which is strained by the external pressure applied to the diaphragm. The transducer requires a constant current source for driving the internal amplifier and the output is then coupled to the appropriate recording device using a blocking capacitor.

The recorder used for the test was furnished by the Fuzes and Sensors Branch of the Air Force Armament Laboratory at Eglin Air Force Base, Florida. Originally developed by MBB (Messerschmitt-Bolkow-Blohm, GmbH), the device featured a single channel input with a solid state memory to record digital data. The maximum sampling rate was one word per 21.9 microseconds and the use of a 7-bit word resulted in an amplitude resolution of one part in 128. The recorder was powered by a rechargeable battery and after being turned on, was capable of operating from six to eight hours on a single charge. The actual writing of data into the recorder memory was initiated by an input signal from the transducer. Any output greater than 5 percent of the full scale signal was sufficient to turn on the recorder and store the data generated. The recorder had been previously used in other projectile test programs using accelerometer as the signal source and the data developed was judged to be satisfactory.

Testing

Figure 7 is a schematic depiction of the instrumentation arrangement as installed in the projectile. The test projectile was derived from the conical nose (Type A) projectile used in the ricochet test program with modifications to accommodate the transducer-recorder package. For the test, the projectile was launched at the center of a 4-inch thick vertical slab target which was one of those constructed for the ricochet test program. The target had a measured compressive strength of 5,542 psi. The projectile struck the target at a 90-degree obliquity angle and with no measurable yaw. The impact velocity as determined from the two high speed cameras was 360.6 and 360.5 ft/sec. The impact velocity measured by the velocity screens was 362.4 ft/sec. Because of the debris cloud and obscuration, the exit velocity of the projectile was only available from one camera and was determined to be 292 ft/sec. The projectile was recovered and the data stored was retrieved from the recorder.

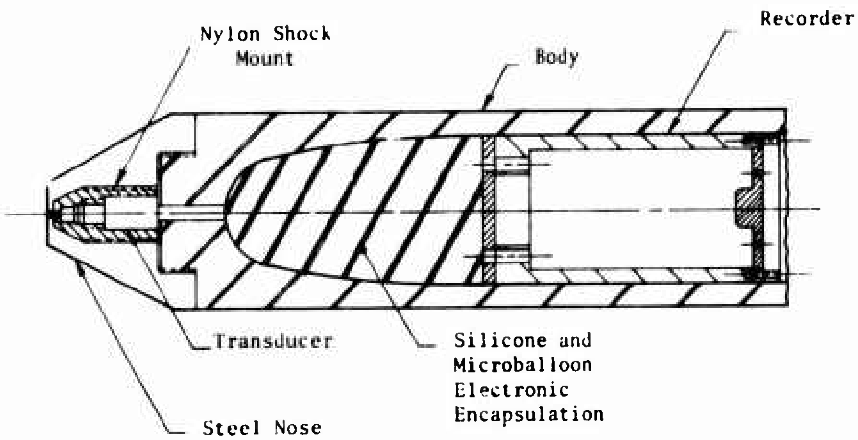


Figure 7. Sectional View of Projectile Design Used For Dynamic Pressure Measurements

Results

Figures 8 and 9 show the data which was generated. The Figure 8 data is the complete record of the event and extends to times well after the projectile had exited the target. Since the transducer was a pressure device, the output indicating negative pressures was obviously erroneous. The large negative signal was believed to be caused by failure of the constant current power supply to the transducer which was battery operated and was found to be shock sensitive after the test. The transducer itself was returned to the manufacturer for checking and recalibration and no failure was evident. Based upon the transit time of the initial elastic wave into the silicone rubber shock attenuator which enclosed the battery, it was estimated that the earliest possible failure time was about 35 microseconds after impact. Figure 9 is an expanded time scale of the early stages of the impact and indicates that the pressure trace was positive for about the first 150 microseconds before going slightly negative (-1,350 psi). Also shown on Figure 9 is a pressure time history derived from a HULL hydrodynamic code calculation of the penetration event. Figure 10 shows the calculational geometry. The pressure trace of Figure 9 shows relatively good agreement with the early portion of the recorded data, the principal difference being the initial stress peak which was not recorded because of the low sampling rate of the recorder. The recorded data also indicates the expected pressure relief in the transition from steady state penetration to the terminal phase in the region from 60 to 90 microseconds. Beyond 90

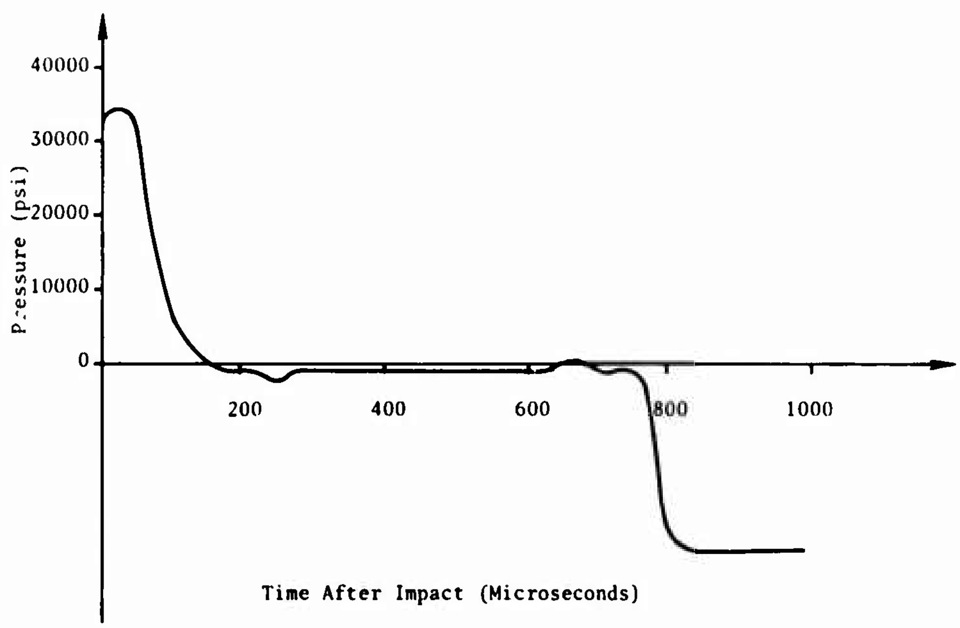


Figure 8. Recorded Pressure Record For First Millisecond

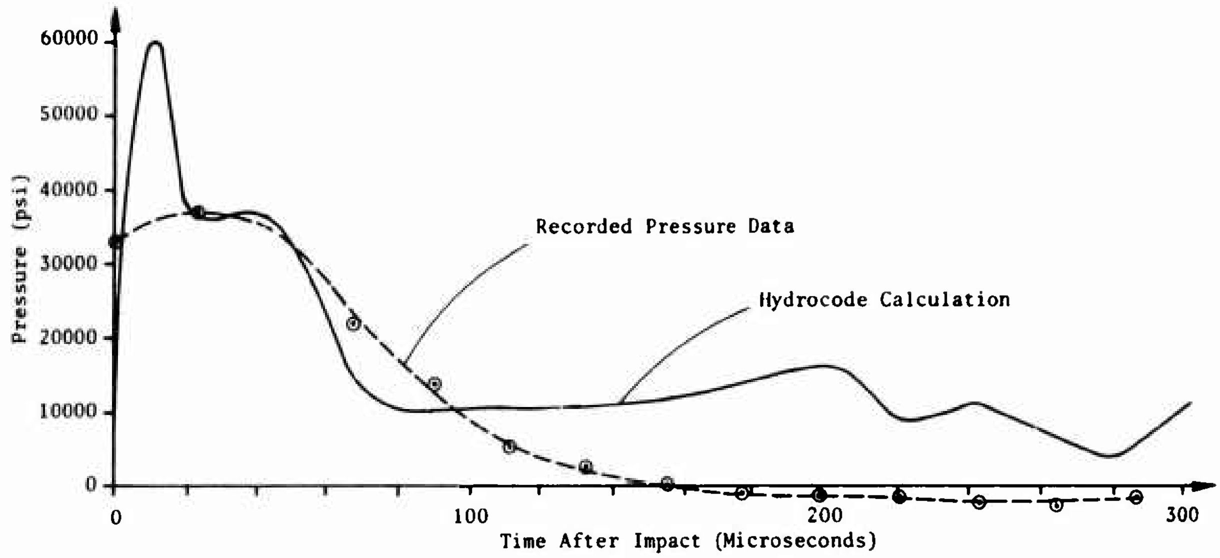


Figure 9. Early Time History Comparison of Recorded and Calculated Pressure

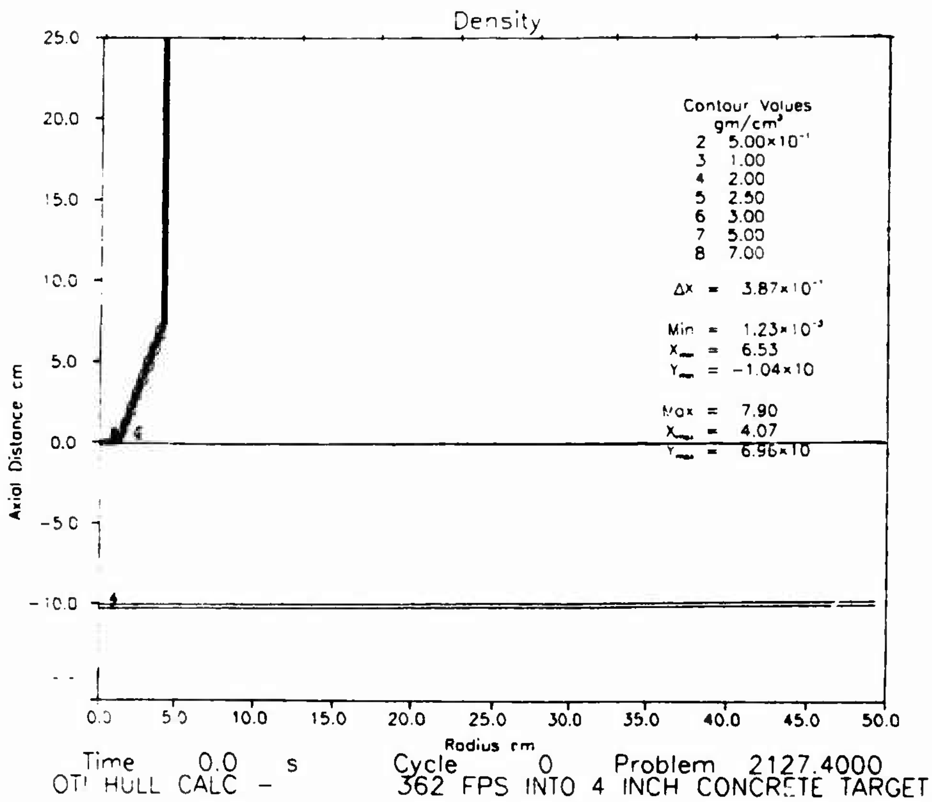


Figure 10. Calculation Geometry

microseconds, the calculated pressures are due to the loading caused by fractured concrete as it is forced ahead of the projectile. The recorded data did not show this loading, but the failure to do so was not completely unexpected since the transducer face was recessed about 0.060 inch from the front face of the projectile and the opening was only about 0.090 inch in diameter. Thus, concrete or aggregate particles much larger than 0.1 inch could have effectively blocked the transducer opening and prevented a signal from being generated at the diaphragm.

Summary

The program described above developed ricochet data for two types of projectiles and the results showed good agreement with an empirical correlation developed from a larger but different data base. A method was developed to record the pressure generated on the nose of a projectile during concrete penetration. Within limitations of the off-the-shelf equipment used, the data showed good agreement with a hydrodynamic code calculation of the event.

References

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